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POSSIBLE APPLICATION OF γ-RAY SPECTROMETERS BASED ON CdZnTe DETECTORS

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New semiconductor γ-ray detectors based on CdZnTe have been developed in the last few years, and they are now being widely used. Their advantages are small size and possibility of operating without cooling. In the present work, these detectors are used to measure the radiation from spent fuel assemblies in holding ponds and dry storage sites, unirradiated nuclear materials, and radioactive wastes. The results are analyzed and compared with other types of detectors. The possible applications of CdZnTe-type detectors are determined.

New CdZnTe-based semiconductor γ-ray detectors have been under intensive development during the last decade. Such detectors are finding increasingly wider applications monitoring spent nuclear fuel and radioactive wastes [1, 2].

With respect to energy resolution, CdZnTe detectors fall between scintillation and germanium detectors, and even though they are small, their γ-ray detection efficiency is satisfactory. In contrast to germanium detectors, they do not require cooling by liquid nitrogen.

The CdZnTe detectors manufactured by the BSI Company (Latvia) are built in the form of a probe which incorporates a miniature CdZnTe crystal and a preamplifier placed in a sealed 8 mm in diameter and 90 mm long metal case. The small size of the probe and the fact that it need not be cooled make it possible to perform measurements in locations which are difficult to access. The small size makes it possible to protect the CdZnTe detector quite simply from scattered γ rays and to collimate the beam of detected γ-rays.

In the present paper, the application of CdZnTe detectors for various measurements is described. Two detectors, whose characteristics are given in Table 1, were used in the experiments. The efficiency of detection of ^{137}Cs γ-rays by detectors differed by approximately a factor of 10.

The detecting apparatus consisted of two different electronic channels – a spectrometric system Multispectrum (BSI, Latvia), intended for operating with detectors of the type given, and a collection of ORTEC modules in the NIM standard with an ADC board built into the computer (NPTs Aspekt, Dubna).

Measurement of the γ-Ray Spectrum of Spent Fuel Assemblies from IRT at Moscow Engineering Physics Institute. Control measurements of spent fuel assemblies, stored in holding ponds and dry storage areas, from different reactors are an important and large problem. CdZnTe detectors, which are small and are capable of operating in intense radiation fields, are suitable for such measurements. In the present work, experiments with fuel assemblies, whose burnup reached 52% and cooldown time exceeded 4 yr, were performed.

In the first experiment, IRT-3M fuel assemblies [3] were placed in a reloading container in a manner so that the central section of the container was located opposite the collimation opening (16 mm in diameter). Both detectors were placed on the axis of the γ-ray beam 50 cm from the container wall. To measure the spectra of the fuel assemblies, the detectors were

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TABLE 1. Characteristics of the CdZnTe Detectors Employed

Characteristics	Detector	
	1	2
Crystal dimensions, mm	3.4 × 3.4 × 1.7	2.3 × 2.3 × 1.1
Probe dimensions (diameter × length), mm	8 × 90	8 × 90
Energy resolution, keV		
E_γ =122.1 keV (^{57}Co)	6.1	3.2
E_γ =661.7 keV (^{137}Cs)	11	6.3

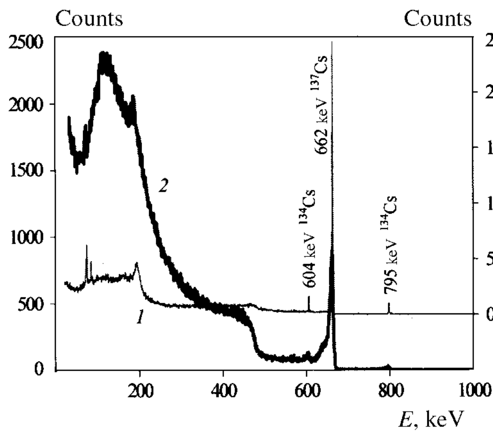

Fig. 1. γ-Ray spectra of a spent IRT fuel assembly, measured with coaxial HPGe (*1*) and CdZnTe (*2*) detectors No. 2.

connected successfully to the multispectrum unit. The count rate reached ~50,000 counts/sec for the first and ~5000 counts/sec for the second detector. A detector made of ultrapure germanium (HPGe) was also placed on the beam axis but 7 m from the container behind a 10 cm thick lead protective wall, which had a 10 mm in diameter collimation opening. This measurement geometry ensured a total load ~5000 counts/sec in the spectrometric channel [4].

The HPGe and CdZnTe detectors were used to measure the γ-ray spectra of three fuel assemblies with different degrees of burnup (Fig. 1). The γ-ray spectra of the spent fuel assemblies with cooldown time exceeding 5 yr contain peaks due to the fission products of ^{137}Cs (661.6 keV) and ^{134}Cs (604.6 keV and 795.8 keV); these peaks contain information about the degree of burnup of the fuel. The energy resolution of the detectors was sufficient to separate these peaks.

During the second experiment, the fuel assemblies were placed in a reactor pool at a depth of about 7 m. The detector was brought up to the fuel assembly to within a distance ranging from 0.5 m up to several centimeters. The main problem of the measurements was the intense radiation field produced in the water around the fuel assembly. The detector had to be surrounded by approximately 5 cm thick lead shielding with a 5 mm in diameter collimation opening directed toward the fuel assembly. The total load, even for measurements with the second detector, reached 150,000 counts/sec, and the spectrometer could operate normally only if a multispectrum electronic unit was used. To avoid touching the water, the detector was placed in a sealed stainless steel case. The metal housing of the probe was additionally isolated from the case to prevent formation of a parasitic grounding circuit, which would degrade the energy resolution of the spectrum. The γ-ray spectra of the fuel assembly in the pool were similar to those obtained in the first experiment.

In the third experiment, γ-scanning of a section of the dry storage site, which contained spent ÉK-10 fuel assemblies off-loaded from the reactor core about 20 years ago was performed. Fuel assemblies with burnup ranging from 4 to 25% were

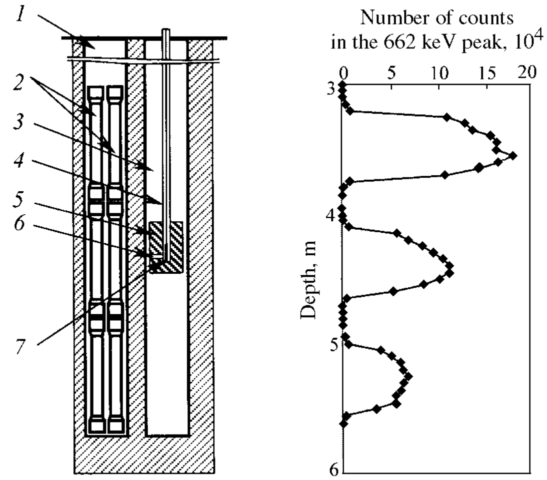

Fig. 2. Scheme of the measurements of γ rays from spent IRT fuel assemblies in a dry storage site and the burnup distribution of the fuel assemblies: *1*) channel for the dry storage site for the fuel assembly; *2*) spent fuel assembly; *3*) measurement channel; *4*) detector holder; *5*) detector shielding; *6*) collimation opening; *7*) CdZnTe detector.

placed in tiers in special boxes, each containing three assemblies (Fig. 2). The detector was placed along the vertical axis in a neighboring section of the dry storage site with a spacing of 5 cm. Thus, the γ-radiation from the fuel assemblies was measured through an approximately 50 mm thick layer of concrete. The measurement probe was equipped with lead shielding with an 8 mm in diameter collimation opening. The maximum total load in the measuring channel was 25000 counts/sec, and the time for a single measurement was 2–3 min. The observed difference in the intensity of ^{137}Cs radiation is explained by the different degree of burnup of the fuel assemblies and by the arrangement of the fuel assemblies with respect to the detector during the measurements.

Analysis of the Spectra. Difficulties arose when the peaks in the spectra were analyzed. The ^{137}Cs 661.7 keV peak is asymmetric; a peak due to emission of cadmium γ-rays appears on its left-hand shoulder. The separate photopeak is essentially the sum of two peaks, and the shape of the peak in the observed spectrum depends on the resolution and the volume of the crystal. Consequently, mathematical models which are used for analyzing spectra obtained with Ge detectors can lead to substantial errors.

A method of analysis implemented in the LSRM computer program (All-Russia Scientific-Research Institute of Physicotechnical and Radioelectronic Measurements) was used to calculate the areas of the photopeaks. Two sample peaks at the start and end of the experimental energy range are calculated when a specific detector is calibrated using standard γ-ray sources. Next, a linear superposition of these two sample peaks is used to analyze the measured spectrum. The LSRM analysis of the γ spectra gave satisfactory results. The ratio between the areas of the ^{137}Cs photopeaks in the spectrum obtained for various fuel assemblies in CdZnTe spectrometers were identical, within the limits of error, with the results obtained in similar measurements using a HPGe spectrometer.

Measurement of γ-Radiation from Unirradiated Nuclear Materials. A second detector was used to measure the γ-radiation spectra of blocks of metallic natural uranium, VVÉR fuel elements with uranium dioxide with 3.6% enrichment (Fig. 3), and a plutonium sample. Analysis of the spectra led to the following conclusions:

• photopeaks belonging to ^{235}U and ^{238}U are observed in the γ-ray spectra of uranium samples; the enrichment cannot be determined from measurements near 100 keV because the resolution is too low;

• the energy resolution of the detectors is adequate to identify isolated photopeaks – 143.8 and 185.7 keV, due to α decay of ^{235}U, and photopeaks at 766.4 keV and 1001 keV, belonging to ^{234m}Pa, a product of the α decay of ^{238}U, in the γ-ray spectrum of uranium samples with different enrichment; this makes it possible to use the infinitely thick sample method to perform control measurements of the enrichment of uranium fuel elements, uranium blocks, fuel assemblies, and so on; the accu-

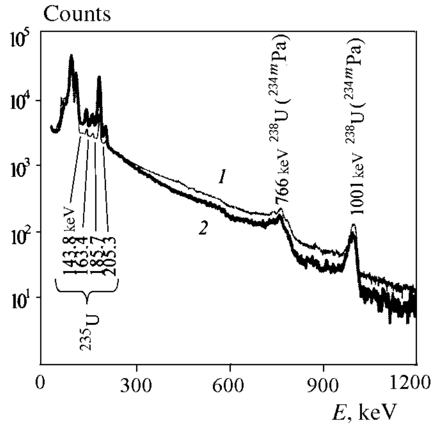

Fig. 3. γ-Ray spectra of blocks of natural uranium (*1*) and fuel elements with UO_2 with 3.6% enrichment (*2*). The spectra were measured with the No. 1 CdZnTe detector.

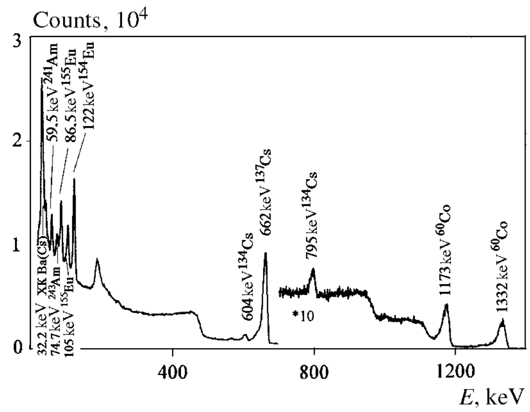

Fig. 4. γ-Ray spectrum of a sample of graphite from a ADÉ-3 reactor at the Siberian Chemical Combine. The spectrum was measured with a No. 1 CdZnTe detector.

racy achieved in measuring the enrichment is higher than in similar measurements using NaI detectors, since the peaks are isolated and the peak/background ratio is better; in principle, the ratio of the number of ^{235}U and ^{238}U nuclei can be determined on the basis of the ^{235}U and ^{238}U γ-rays using the FRAM computer program, but this requires that the program be updated, since the photopeak model used in the program does not correspond to the shape of the peaks in the spectra obtained with CdZnTe detectors; the total load of the measuring channel in such measurements is low, so that the spectrometric channel can be assembled from units in the NIM standard and in the units produced by NPTs Aspekt; the measurement time depends on the detector volume and the properties of the sample (mass, geometry, and others) and can be tens of minutes.

The spectra of plutonium samples have a more complicated structure and contain many closely-spaced lines belonging to different plutonium isotopes. The resolution of CdZnTe detectors in all energy ranges is inadequate for observing individual peaks (except for the 59.4 keV ^{241}Am peak), even if detectors with a small volume (better resolution) are used, so that CdZnTe detectors are hardly suitable for isotopic analysis of plutonium samples.

Measurement of γ-Radiation from Radioactive Wastes. A CdZnTe detector was also used to measure γ radiation from samples of graphite from decommissioned commercial reactors (Fig. 4). Peaks belonging to γ radiation from ^{60}Co,

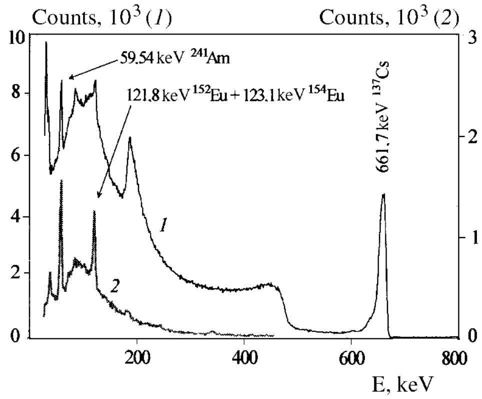

Fig. 5. γ-Ray spectra of soil samples from the region of the accident at the Chernobyl nuclear power plant (Belarus, village Masany, Gomel' oblast) (*1*) and from the Semipalatinsk test area ("Opytnoe pole" site) (*2*).

^{134}Cs, ^{137}Cs, ^{154}Eu, ^{155}Eu, ^{241}Am, and ^{243}Am are observed in the spectrum. These peaks are all isolated and can be analyzed mathematically, showing that CdZnTe detectors are suitable for investigating the radioactive contamination of graphite. These detectors can be used to probe graphite masonry from decommissioned commercial reactors and for investigations inside disposal sites for radioactive wastes and in the wells around them.

Measurement of Radioactive Contamination of Soil. The first detector was used to measure the radioactive contamination of soil (Fig. 5). The mass of the soil sample was about 50 g, and the ^{241}Am activity was 500–1000 Bq/kg.

CdZnTe detectors make it possible, aside from ordinary methods of measuring soil (sampling or field measurements with a detector placed on a carriage on the surface being studied), to place a detector in a well at a depth up to 10 cm (according to published data, a layer of this thickness ordinarily contains 90% of the radionuclides). This makes the method much more sensitive, since the measurements will be performed in a 4π geometry.

In summary, investigations have shown that CdZnTe detectors have useful applications. There are other prospects for using such detectors, for example, monitoring technological processes during the production of nuclear materials and monitoring γ-rays from liquid radioactive wastes. When high resolution is not needed, and the most important aspect is operational simplicity (operating without cooling with liquid nitrogen) and compactness, then CdZnTe detectors have an advantage.

It is unlikely that CdZnTe spectrometers will replace NaI and Ge spectrometers, as asserted in [2]. More likely, the CdZnTe spectrometers will supplement the arsenal of spectroscopic instruments.

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